

THE PROBING IN-SITU WITH NEUTRON AND GAMMA RAYS (PING) INSTRUMENT FOR PLANETARY COMPOSITION MEASUREMENTS

A. Parsons¹, J. Bodnarik¹, L. Evans^{1,2}, T. McClanahan¹, M. Namkung¹, S. Nowicki^{1,3}, J. Schweitzer⁴, R. Starr^{1,5}

¹NASA Goddard Space Flight Center, Code 691, Greenbelt, MD 20771 (Ann.M.Parsons@nasa.gov), ²Computer Sciences Corporation, ³University of Michigan, ⁴University of Connecticut, ⁵Catholic University of America,

Introduction: The Probing In situ with Neutrons and Gamma rays (PING) instrument (formerly named PNG-GRAND) [1] experiment is an innovative application of the active neutron-gamma ray technology successfully used in oil field well logging and mineral exploration on Earth over many decades. The objective of our active neutron-gamma ray technology program at NASA Goddard Space Flight Center (NASA/GSFC) is to bring PING to the point where it can be flown on a variety of surface lander or rover missions to the Moon, Mars, Venus, asteroids, comets and the satellites of the outer planets and measure their bulk surface and subsurface elemental composition without the need to drill into the surface.

Gamma-Ray Spectrometers (GRS) have been incorporated into numerous orbital planetary science missions. While orbital measurements can map a planet, they have low spatial and elemental sensitivity due to the low surface gamma ray emission rates resulting from using cosmic rays as an excitation source. PING overcomes this limitation *in situ* by incorporating a powerful neutron excitation source that permits significantly higher elemental sensitivity elemental composition measurements.

PING combines a 14 MeV deuterium-tritium Pulsed Neutron Generator (PNG) with a gamma ray spectrometer

neutrons allows such sub-surface composition measurements to be made without the need to drill into or otherwise disturb the planetary surface, thus greatly simplifying the lander design. We are currently testing a PING prototype at a unique outdoor neutron instrumentation test facility at NASA/GSFC that provides two large (1.8 m x 1.8 m x .9 m) granite and basalt test formations placed outdoors in an empty field. Since an independent trace elemental analysis has been performed on both these Columbia River basalt and Concord Gray granite materials, these large samples present two known standards with which to compare PING's experimentally measured elemental composition results.

We will present both gamma ray and neutron experimental results from PING measurements of the granite and basalt test formations in various layering configurations and compare the results to the known composition.

Principles of Operation: An active neutron – gamma ray instrument consists of three basic components: 1) a PNG that emits intense pulses of fast (14 MeV) neutrons to excite materials at and below the planetary surface, 2) a gamma ray spectrometer to measure the characteristic gamma rays emitted by the excited elements and 3) neutron detectors to measure the resulting lower energy epithermal and thermal neutrons that reach the surface. To improve elemental sensitivity by reducing background, aiding in gamma ray line identification and studying the neutron moderation properties in the material, both the energy and the time of each neutron and gamma ray event between PNG pulses is measured by the PING electronics and is used in the analysis of the data.

When a planetary surface is bombarded with 14 MeV neutrons from the PNG, the nuclei in the planetary materials down to ~ 50 cm below the surface are excited so that they emit gamma radiation characteristic of the elements present. The intensity of these gamma ray lines as measured by the gamma ray spectrometer can be used to determine the absolute abundance of each element in the material. Also, neutrons are scattered and captured within the material and a measurement of the time variation of the surface thermal and epithermal neutron flux between PNG pulses yields two important pieces of information: 1) The epithermal neutron die-away rate is used to infer the moderating properties of the material such as the bulk hydrogen content and subsurface layering configurations. 2) The die-away profile of the thermal neutrons provides a check on the gamma ray-derived elemental composition by producing a measurement of the total macroscopic cross section of the material. Elements accessible to PING

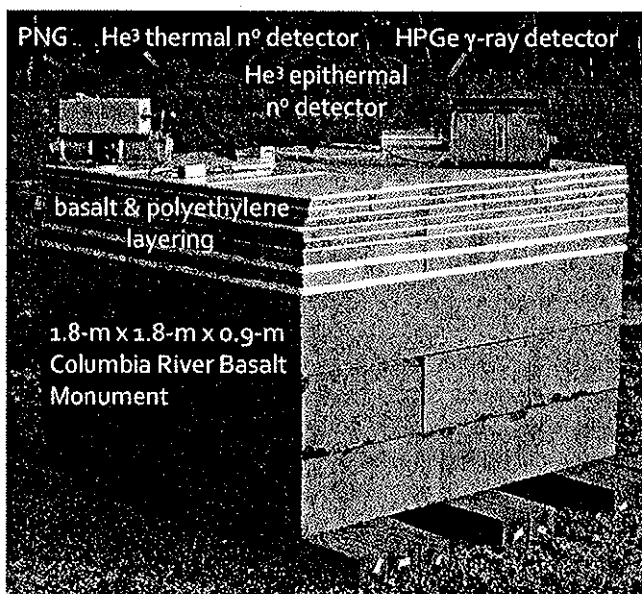


Figure 1: Photo of PING components on top of the asteroid analog created by alternating layers of HD polyethylene and basalt on top of the basalt monument.

and two neutron detectors to produce a landed instrument that can determine the elemental composition of a planet down to 30 – 50 cm below the planet's surface. The penetrating nature of .5 – 10 MeV gamma rays and 14 MeV

include C, H, O, P, S, Si, Na, Ca, Ti, Fe, Al, Cl, Mg, Mn, V and the naturally radioactive elements K, Th, and U.

Description of the Neutron and Gamma Ray Instrumentation Test Facility:

The test facility at GSFC's Geophysical and Astronomical Observatory (GGAO) consists of the large basalt and granite test formations located in the middle of an open field surrounded by a 50-meter radius radiation safety perimeter. Operating outdoors in a large empty field minimizes the background due to neutron and gamma ray interactions with nearby structures. The facility is equipped with a nearby operations building that provides power and communications to both the basalt and granite monuments so that users can operate and monitor PING at a safe distance from its neutron generator. The radiation safety perimeter is visually monitored during operation.

Our facility allows us to perform layering studies using 2.5 and 5 cm thick basalt and granite plates and 2.5 cm thick high-density polyethylene plates to simulate layers of water ice. These and other materials can be stacked on top of either sample to simulate a variety of layering scenarios. We have also added alternating thin (2.5 cm) layers of basalt and polyethylene plates on top of the basalt to physically simulate a homogeneous soil with a higher carbon and hydrogen content than the bare basalt such as needed to produce an analog of a carbonaceous asteroid. This asteroid analog is used to study how sensitive PING would be to composition differences in this asteroid class. Figure [1] is a photograph of our multi-layered asteroid configuration.

Time-Gated Gamma Ray Spectra: A great advantage of using a PNG is the ability to identify the nuclear process (inelastic scattering, thermal neutron capture, delayed activation or natural radioactivity) that is responsible for specific gamma ray lines in the spectrum. The experiment is controlled by multiple Digital Signal Analyzers [2] that permit operation in event-by-event time stamped list mode. With the detection time of gamma ray known, it is possible to select events by their detection time with respect to the neutron pulse and produce separate gamma ray spectra for different time windows. Since there is a time delay in the emergence of thermal neutron capture gamma rays as the material moderates the 14 MeV neutrons, we can use the event arrival time to identify the gamma rays resulting from the different nuclear processes. The ability to isolate gamma rays by their timing will improve the instrument sensitivity tremendously and is a valuable tool for identifying interfering spectral peaks. Using this technique with different gamma ray spectrometer technologies we will show how identifying the nuclear process by the gamma rays' arrival time relative to the PNG pulse simplifies the spectral analysis and improves sensitivity.

Results: Elemental composition results derived using both gamma ray and neutron data will be presented and compared to the elemental composition of the granite and

basalt monuments. Neutron die-away data data such as shown in Figure 2 below, will also be shown. This "die-away" curve, the histogram of the time of detection of surface neutron emission with respect to the time of each fast neutron pulse from the PNG, shows both the moderation of the neutrons and their subsequent capture by the materials' nuclei. As can be seen by the decomposition of data from a the double exponential fit to two single exponential fits (green and blue), the data is best fit by the green single exponential fit due to the fact that right after the PNG pulse window there is a period of time where there are two competing processes of epithermal neutrons being moderated/thermal neutrons being created and thermal neutrons being absorbed. It is not until later during the PNG pulse period that the thermal neutrons are only being absorbed by the basalt monument, and we use the fit to this portion of the data to determine the experimental average macroscopic thermal neutron absorption cross-section of the bulk material. With PING, we can demonstrate our ability to detect a layer of HD polyethylene 5 cm beneath the surface. By selecting gamma ray data according to the time of arrival between the neutron bursts, we are also able to isolate gamma ray spectra primarily due to

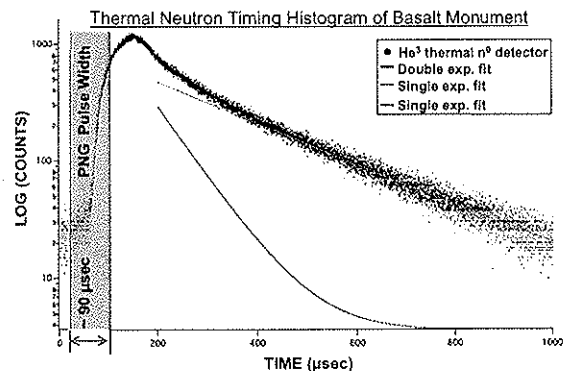


Figure 2: is an example of the experimental thermal neutron timing histogram for the basalt monument. The thermal neutron timing histogram is a plot of 2 hours of experimental data (red) from the He3 thermal neutron detector that was binned by the PNG pulse period of 1000 μ s.

inelastic scattering and thermal neutron capture (Figure 2). We have made measurements both with and without 2.5 cm of polyethylene on the granite and covered with 5 cm granite plates. The absence of hydrogen when the polyethylene is not present demonstrates the ability of this technique to measure subsurface hydrogen. The lack of evidence of the 3539 keV capture line from Si in the inelastic spectrum will illustrate how well this technique isolates the gamma rays from inelastic processes. This presentation of real data provides an excellent demonstration of PING's capabilities.

References: [1] Parsons, A, J Bodnarik, et. Al. 'Active Neutron and Gamma-Ray Instrumentation for in Situ Planetary Science Applications', *Nuclear Instruments and Methods -A*, 652 (2011), 674-679

[2] The Lynx Digital Signal Analyzer from Canberra